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ABSTRACT

This document presents a preliminary review of the communications and tracking systems of the ground-based support and space vehicle elements to be used in the first four missions of the Apollo Applications Program (AAP). The communication and tracking systems are described that are currently planned to be carried in the Airlock, the CSM, the LM&SS rack, the LM, the ATM rack and the Uprated Saturn I Launch Vehicle. The communications and tracking support that can be provided by the existing MSFN is also reviewed.

Potential problem areas are noted and discussed in the space vehicle communications and tracking systems and in the MSFN support for the first four AAP missions. These include: (a) the lack of definition of functional and operational requirements, (b) the lack of a precise definition of the communications requirements of experiment packages, (c) the national objective of vacating the VHF telemetry band by 1970, (d) real-time MSFN support of the space vehicle telemetry links, (e) capability of the MSFN to support multiple concurrent missions, (f) electromagnetic compatibility of the space vehicle cluster, (g) space vehicle antenna system design, (h) communications link performance and (i) the need for a space vehicle communication and tracking system equipment implementation trade-off analysis.

Alternatives to the planned equipment implementation of the communications and tracking systems of the space vehicle modules are reviewed and desirable alternatives are identified.

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FROM: A. G. Weygand

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TECHNICAL MEMORANDUM

1.0 Introduction

The purpose of this document is two-fold: (a) to compile the communications and tracking functional requirements and information on the systems configuration being implemented on the space vehicles and the communications and tracking operational support requirements for the first four missions of the Apollo Applications Program (AAP) and (b) to provide a preliminary review of the communications and tracking systems of the ground-based support and space vehicle elements to be used in the first four missions of the AAP with the objective of identifying open requirements and underlining possible problem areas. The first four missions of the AAP to be discussed in this document (with reference to the space vehicle elements applicable to the mission) include: (a) AAP-1 (CSM and Lunar Mapping and Surveying System rack), (b) AAP-2 (Airlock and S-IVB stage Workshop), (c) AAP-3 (CSM with resupply capabilities), (d) AAP-4 (LM and the Apollo Telescope Mount rack), (e) joint mission A (CSM, LM & SS, Airlock and S-IVB stage Workshop), and (f) joint mission B (CSM, LM & SS, LM, ATM, Airlock and S-IVB stage Workshop).

Section 2.0 is a compilation listing of the communications and tracking functional requirements on the Airlock and S-IVB stage Workshop, the CSM, the LM, the ATM, the Uprated Saturn I Launch Vehicle and the Manned Space Flight Network (MSFN) as they exist in diverse documentation or as they can be inferred by the equipment implementation planned for the various space vehicle elements or modules. Special note should be taken of the lack of definitive communications and tracking functional requirements for the combinations of these modules as will occur during the joint AAP missions.

The current equipment implementation plan for the communications and tracking systems of the Airlock, LM & SS, LM, ATM, CSM, and Uprated Saturn I Launch Vehicle are described in Section 3.0. Since the LM, the CSM and the Uprated Saturn I

Launch Vehicle will be instrumented almost identically to the corresponding modules in the Apollo Program, little detail is included in the description of their respective communications and tracking systems and the reader is referred to current Apollo Program documentation to obtain more detailed information.

The communications and tracking support capabilities of the existing MSFN (although some of the capabilities included are funded, they are subject to implementation schedule for availability) are described in Section 4.0. The impact of the support requirements for the first four AAP missions on the MSFN are also discussed in Section 4.0 but only to a degree permitted by the lack of a definitive set of mission operational requirements.

A discussion of the potential problem areas in the space vehicle communications and tracking system configuration and ground-based support for the first four AAP missions is presented in Section 5.0. With the potential problem areas in mind, alternatives to planned equipment implementation in the space vehicle modules of the telemetry, up-data and voice communications functions are presented and discussed in Section 6.0. Conclusions and recommendations stemming from the review appear in Section 7.0.

2.0 Functional Requirements

2.1 Ground Rules

(a) Make maximum use of existing flight qualified hardware.

(b) Maintain to the maximum extent possible a policy of "no changes" necessary to the CSM, the Spacecraft-LM Adapter (SLA), the LM and the S-IVB/IU with respect to the requirements of AAP missions 1 through 4, inclusive. Any modifications to spare CSMs (Block II) from the Apollo Program for use in these AAP missions to be limited to those which can be accomplished at the launch site.

(c) Include provisions for one or two suited crewmen to operate in the Airlock, in the S-IVB tank, in the LM, in free space, or in any combination of the above while at least one crewman remains in the CM.

(d) The Uprated Saturn I Launch Vehicles used in these AAP missions will be instrumented nominally in the same manner as the Uprated Saturn I Launch Vehicles used in the Apollo-Saturn Program and will have the same basic telemetry, up-data and tracking functional requirements.

(e) The CSMs used in these AAP missions will be instrumented nominally in the same manner as the Block II CSMs used in the Apollo-Saturn Program with possible slight modifications made at the launch site and will have the same basic telemetry, up-data and tracking functional requirements as defined for operational CSM Earth orbital missions in the Apollo-Saturn Program.

(f) The LM used in these AAP missions will be the nominal ascent stage of the LM to be used in the lunar landing mission of the Apollo Program minus the major propulsion capability and with possible slight modifications made at the launch site; however, the basic telemetry, up-data and tracking functional requirements will be the same as defined for operational LM Earth orbital missions in the Apollo-Saturn Program.

2.2 Space Vehicle

2.2.1 Voice Communications Functional Requirements

(a) Incorporate the capability for voice communications between any two of the three crewmen whenever any portion of the space vehicle is manned, including the periods when any of the crewmen have egressed the CM into space or have entered the Airlock, the S-IVB tank, or the LM.

(b) Incorporate the capability for duplex voice conferencing among the three crewmen and among the three crewmen and the MSFN (assuming a MSFN station is within line-of-sight of the space vehicle) during all periods of the mission when any portion of the space vehicle is manned.

(c) Incorporate the capability for on-board recording of voice communications among the crewmen, and the capability for subsequent delayed playback of the recorded voice communications concurrent with and independent of real time voice communications between the crewmen and the MSFN.

2.2.2 Crewmen Biomedical Data Functional Requirements

(a) When one, two, or three crewmen are in the CM, provide the capability for the sequential transmission of biomedical data from each crewman in the CM to the MSFN.

(b) During periods when one or two crewmen are external to the CM (in the Airlock, the S-IVB workshop, or the LM or engaged in activities in space), provide the capability for:

(1) on-board recording of biomedical data of the one or two (simultaneously) crewmen external to the CM for delayed playback transmission to the MSFN,

(2) real time transmission to the MSFN of biomedical data of one or two (simultaneously) crewmen external to the CM.

2.2.3 Tracking Functional Requirements

There have been no requirements defined for the LM&SS rack, the ATM rack, or the Airlock to provide active assistance to the MSFN or to the CSM to facilitate tracking for orbit determination or for rendezvous.

2.2.4 Up-Data Functional Requirements

(a) Incorporate the capability to enable stations of the MSFN to command certain functions on-board the LM &SS rack, the ATM rack, and the Airlock or modes of operation of selected systems of the LM &SS rack, the ATM rack, and the Airlock.

(b) Incorporate provisions in the LM &SS rack, the ATM rack, and the Airlock for supplying an indication of reception of a valid up-data message and/or indication of completion of the commanded action to a telemetry system for transmission to the MSFN.

(c) Up-data reception capability to the LM &SS rack, the ATM rack and the Airlock required from activation of the LM &SS rack, the ATM rack, and the Airlock, respectively, until completion of its active mission.

2.2.5 Telemetry Functional Requirements

The following list of functional requirements apply to the LM&SS rack, to the ATM rack and to the Airlock and S-IVB stage Workshop combination.

(a) Incorporate the instrumentation to collect the necessary data to permit the determination of module systems performance and/or status and to aid in the assessment of the results of some of the experiments being conducted on-board the module.

(b) Incorporate provisions for appropriate timing, calibration, processing, and formatting of data gathered by the module instrumentation into a form suitable for transmission to the MSFN.

(c) Incorporate the capability for on-board recording of selected data gathered on-board the module and the capability for subsequent delayed play-back of the recorded data.

(d) Module system status data required in real time in the launch area during terminal count-down until lift-off to permit a go/no-go decision.

2.2.5.1 Lunar Mapping and Surveying System Rack

(a) LM&SS rack system status data required in real time during those portions of the LM&SS mission when it is active sequentially with the playback of recorded data from the LM&SS experiments.

2.2.5.2 Airlock

(a) Incorporate necessary instrumentation to permit the determination of environmental status of the crew areas (S-IVB stage tank and Airlock) and the bio-medical status of two crewmen in the crew areas.

(b) Real time telemetry required concurrently with playback of recorded data from the Airlock and S-IVB stage Workshop during those portions of the Airlock mission when crewmen are in the vicinity.

(c) Airlock system status data required in real time prior to docking of the CSM to the Airlock multiple docking adapter and periodically during the earth orbital storage of the Airlock and S-IVB stage Workshop.

2.2.5.3 Apollo Telescope Mount Rack

(a) Real time telemetry required concurrently with playback of recorded data from the ATM during those portions of the ATM mission when experiments are being performed.

2.3 Ground-Based Communications and Tracking System Functional Requirements

(a) Primary command and decision-making responsibility shall rest with the Mission Control Center in Houston (MCC-H) and mission control will be remoted through stations of the Manned Space Flight Network (MSFN) from the MCC-H.

(b) The information flow between the stations of the MSFN and the MCC-H must be sufficient to permit the MCC-H to direct mission operations and to coordinate the overall mission from the decision to start mission operations until the mission is completed and includes processed telemetry data, processed tracking data, voice communications, biomedical data, and other message traffic from the stations of the MSFN to MCC-H and command and up-dating information for insertion into the space vehicle, acquisition data, voice communications, and administrative and coordination data from the MCC-H to the stations of the MSFN.

(c) Two-way voice communication capabilities are required in the MSFN as follows:

(1) duplex service between the stations of the MSFN and the crewmen in or around the space vehicle in a conference loop,

(2) reception of playback recorded voice from the the space vehicle without interrupting real-time voice communications with the crewmen,

(3) relay duplex voice communications between the crewmen and the MCC-H.

(d) The MSFN is required to have the capability to transmit data immediately sequentially to the CSM, the LM, the LM&SS rack, the ATM rack, the Airlock and the Uprated Saturn 1 Launch Vehicle, to monitor and verify the transmissions made to the space vehicle and to receive from the telemetry systems of the space vehicle verification of reception of a valid up-data message by the space vehicle.

(e) The MSFN is required to have the capability to track the space vehicle to permit determination of space vehicle position and velocity by MCC-H and/or to track portions of the space vehicle to permit MCC-H to assist the CSM in rendezvousing with another portion of the overall space vehicle.

(f) The MSFN is required to have the capability to receive and record the operational and the engineering or experiment data from all active portions of the space vehicle simultaneously and to decommutate those telemetry links from the space vehicle carrying data required in real-time by MCC-H for mission control and to process the data in real-time for transmission to MCC-H.

(g) The MSFN and the MCC-H are required to support simultaneously an AAP cluster mission, an Apollo-Saturn lunar landing mission and up to three Apollo Lunar Surface Experiments Packages(ALSEP).

3.0 Present Configuration of the Communications Systems of the Component Modules to the Overall Cluster

3.1 Communications Systems of the Uprated Saturn I Launch Vehicle

The Uprated Saturn I Launch Vehicles used in conjunction with these AAP missions will be equipped with a VHF telemetry system, a UHF up-data system, and a C-band radar transponder system which are also carried by the Uprated Saturn I Launch Vehicles used in the Apollo Program. Approximately 7 hours after launch the power supplies for the communications systems of the Uprated Saturn I Launch Vehicle will be exhausted and RF transmissions from the launch vehicle will cease.

3.2 Communications Systems of the Command and Service Module

The CSMs used in conjunction with these AAP missions will be equipped with a Unified S-Band (USB) communications system, a data storage and a VHF communications system which are carried by the Block II CSMs in the Apollo Program and with a C-band radar transponder system which is not carried by the Block II CSMs in the Apollo Program. The functions provided by the CSM USB system using the PM and FM carriers simultaneously include active tracking assistance to the MSFN, up-data reception from the MSFN, real-time telemetry transmission to the MSFN, biomedical data relay from an extravehicular crewman, and voice, voice relay and voice conferencing communications with the MSFN via the PM carrier and include playback of recorded voice, playback of recorded telemetry, real-time transmission of scientific data, playback of recorded scientific data, and television transmission to the MSFN via the FM carrier. The functions provided by the CSM VHF communications system include voice communications with the LM (simplex) or an extravehicular crewman (duplex), biomedical data reception from an extravehicular crewman, and telemetry reception from the LM. The function provided by the data storage system include recording the following for subsequent playback to the MSFN via the USB FM carrier: LM telemetry, voice communications, scientific data, and CSM telemetry.

3.3 Communications Systems of the Lunar Module

The LM used in conjunction with the ATM rack will be equipped with a Unified S-Band (USB) communications system and a VHF communications system which are also carried by the LMs in the Apollo Program. The functions provided by the LM USB system using the PM carrier include active tracking assistance to the MSFN, up-data reception from the MSFN, real-time telemetry transmission to the MSFN, biomedical data relay from an extravehicular crewman, and voice relay, voice conferencing and voice communications with the MSFN. The LM USB system does not have the capability of transmitting the PM and FM carriers simultaneously.

The functions provided by the LM VHF communications system include voice communications with the CSM (simplex) or an extravehicular crewman (duplex), biomedical data reception from an extravehicular crewman, and telemetry transmission to the CSM.

3.4 Communications Systems of the Extravehicular Crewmen

The VHF communications system contained in the portable life support system (PLSS) used by the crewmen in conjunction with the Apollo space suit when performing extravehicular activities will provide the following functions: (a) duplex voice communications with the LM, the CSM, or another extravehicular astronaut, and (b) biomedical (impedance pneumograph) data transmission to the LM and CSM.

3.5 Communications System of the Lunar Mapping and Surveying System (LM & SS) Rack

Under current planning, the LM&SS rack mission will be conducted during that period of time when the LM&SS rack and the CSM are docked and connected by a hardline. Thus, although the LM&SS rack will have an instrumentation and telemetry subsystem, the LM&SS will depend upon the RF telemetry links of the CSM to transfer the necessary data to the MSFN. Similarly, the MSFN will depend upon the up-data link to the CSM and subsequent hardline to the LM&SS rack in order to enter commands in the LM&SS.

The instrumentation and telemetry subsystem of the LM&SS rack processes and formats the various measurements of LM&SS rack systems performance and experiment data into four channels which are hardlined into the CSM. Three of these channels will contain the data pertinent to the LM&SS experiment and the third channel will contain data from other experiments on the LM&SS rack. One of these channels will be recorded on the track used to record LM 1.6 kbs PCM split-phase data in the Apollo Program and the other two channels (either of which may include 10 modulated subcarriers) will be recorded on two of the tracks used for recording scientific data in the Apollo Program. This recorded data will be dumped periodically during the mission via the CSM Unified S-Band (USB) FM link. The fourth channel, which may consist of 10 modulated subcarriers, contains the housekeeping data on the LM&SS rack systems and is used to modulate the CSM USB FM transmitter at baseband in real-time and will not be recorded.

3.6 Communications System of the Airlock

The communications system to be described below is currently included in the contract from NASA to the McDonnell Aircraft Company (MAC), the contractor for the Airlock. The Airlock will be equipped with an independent instrumentation and telemetry system, an independent up-data receiving and decoding system, and an independent voice communications system, and will include two VHF PCM/FM telemetry transmitters, redundant UHF PSK/FM up-data receivers, redundant VHF AM voice transceivers, and a data recorder, all of which are of the variety used in the Gemini Program.

The instrumentation and telemetry system of the Airlock will be capable of processing and combining various measurements of Airlock systems performance, experiment data, biomedical data from up to two crewmen, etc., into a serial binary coded non-return to zero level (NRZ-L) signal of 51.2 kilobits per second (kbs). This PCM wavetrain of 51.2 kbs will be used to modulate a VHF FM transmitter (2 watts output power) in real-time. In addition, the instrumentation and telemetry system will be capable of generating a second PCM wavetrain of 5.12 kbs which most likely will be largely composed of experimental data. The 5.12 kbs PCM wavetrain will be continuously recorded by a tape recorder of the type used in the Gemini Program until the recorder is commanded to playback the recorded data for transmission to the MSFN. The recorder plays back at a higher speed than it records thereby producing a 112.64 kbs output PCM wavetrain. This 112.64 kbs PCM wavetrain will be used to modulate a second VHF FM transmitter (2 watts output power). It should be noted that both telemetry links can be operated simultaneously on a non-interference basis.

The up-data receiving (450 MHz) and decoding system of the Airlock will operate in the same manner as the up-data receiving and decoding system of the ATM rack described in Section 3.7, but will include redundant receivers and decoders.

The Airlock will be equipped with redundant double sideband amplitude modulated (AM) voice transceivers operating at a receiver and a transmit frequency of 296.8 MHz (simplex operation only). This is currently the only means of voice communications between the Airlock and the CSM, the LM, and any EVA. Voice communications between the Airlock and the MSFN will be accomplished by relay through the CSM; CSM/Airlock at VHF and CSM/MSFN at S-band.

The antenna system of the Airlock will consist of two stub antennas located 90° apart on the stationary portion of the SLA and a stub antenna near the docking ring of the Airlock 180° apart from one of the stub antennas on the SLA. The two telemetry transmitters, one voice transceiver and one up-data receiver will be multiplexed and fed through a switch to either the antenna near the docking ring or to the stub antenna on the

SLA 180° apart from the docking ring antenna. The switch will be operated by commands from the MSFN via the up-data link. The second up-data receiver and the second voice transceiver will be multiplexed and fed to the second stub antenna located on the SLA.

3.7 Communications System of the Apollo Telescope Mount (ATM) Rack

Under current planning, although the ATM rack and the LM ascent stage are never separated during the mission, the ATM will be equipped with an independent instrumentation and telemetry system, a data recorder, an independent up-data receiving and decoding system, including two VHF PCM/FM telemetry transmitters and one UHF up-data receiver, all of which are of the variety used in the Uprated Saturn I Launch Vehicle used in the Apollo Program.

The instrumentation and telemetry system will be capable of processing and combining various measurements of ATM subsystems performance, results of experiments, etc., into a serial binary coded non-return-to-zero level (NRZ-L) signal of 72 kilobits per second (kbs) where a "one" is represented by one level and a "zero" is represented by another level. This PCM wavetrain of 72 kbs will be used to modulate a VHF FM transmitter in real-time. In addition, the instrumentation and telemetry system will be capable of processing and combining only the experiment data (which is also included in the 72 kbs real-time data stream) into a serial binary coded NRZ-L signal of 4 kbs. This PCM wavetrain of 4 kbs will be fed continuously to a recorder on-board the ATM rack. During the periods of the ATM active mission when the ATM is not within line-of-sight of a station of the MSFN, the recorder will record the 4 kbs PCM wavetrain continuously. During the periods of the ATM active mission when the ATM is within line-of-sight of a station of the MSFN, the recorder will be commanded to playback the stored data. The recorder will playback the recorded data at a rate of 72 kbs. This 72 kbs PCM NRZ-L wavetrain will be used to modulate a second VHF FM transmitter. It should be noted that the two telemetry links can be operated simultaneously on a non-interference basis. The outputs of the two telemetry transmitters will be multiplexed and used to feed the VHF antenna subsystem of the ATM. The VHF antenna system currently consists of two slot antennas, one located near the end of one of the four solar panels and the other located near the end of the solar panel diametrically opposite to the first solar panel.

The up-data receiving and decoding system will be capable of detecting 450 MHz carrier frequency modulated by a 2 KHz tone phase shift keyed (PSK) by a serial binary bit stream of 1000 bits per second and decoding the bit stream consisting of 5 bit subcoded words to derive the up-data information bits at a corresponding rate of 200 bits per second and of routing the commands to the proper location. The up-data decoding system will determine whether or not the received message is a valid message and will provide a signal to the telemetry system when applicable for transmission to the MSFN indicating reception of a valid up-data message. The UHF antenna system which will feed the up-data receiving and decoding systems will consist of two UHF slot antennas located near the end of the same two solar panels used to mount the VHF slot antennas.

Umbilical lines will be provided to facilitate pad checkout during terminal countdown.

4.0 Impact on the Manned Space Flight Network

In general, the MSFN, as currently configured, is compatible with both the VHF and Unified S-Band (USB) telemetry systems, both the C-band and USB tracking systems, both the UHF and USB up-data systems, and USB voice communications systems to be carried by the space vehicle modules of the first four AAP missions as described in Section 3.0. Furthermore, the MSFN is capable of decommutating PCM NRZ-L bit streams of either 51.2 or 72.0 kilobits per second in the formats to be used in these AAP missions and each station of the MSFN has adequate tape storage capability to record all of the voice and telemetry received by that station. Subject to current implementation schedules, the space-vehicle support capabilities of each station of the MSFN are summarized in Table 4.1.

TABLE 4.1

Communications and Tracking
Support Capabilities of Stations of the MSFN

STATION	USB PM Xmt.	USB PM Rec.	USB FM Rec	UHF Up-Data	VHF Telemetry	C-Band Radar	PCM Decom
MIL & MLA	2	2	2	X	X	X	3
GBM & GBI	1	2	1	X	X	X	4
ANG & ANT	1	2	1	X	X	X	4
BDA	1	2	1	X	X	X	4
ACN & ASC	2	2	2		X	X	3
CYI	1	2	1	X	X	X	3
MAD - 85'	2	2	2				3
TAN					X		
CRO	2	2	2	X	X	X	3
CNB - 85'	2	2	2				3
GWM	2	2	2		X		3
HAW	2	2	2	X	X	X	3
GDS - 85'	2	2	2				3
GYM	1	2	1		X		3
WHS						X	
TEX	1	2	1	X	X		3
VAN	2	2	2	X	X	X	3
MER	2	2	2	X	X	X	3
RED	2	2	2	X	X	X	3

The communications and tracking support of an Apollo-Saturn space vehicle provided by stations of the Department of Defense, the Kennedy Space Center, and the MSFN during the launch phase of a mission in the Apollo Program will be adequate to support the space vehicle during the launch phase of any single mission of the first four AAP missions. Similarly, the communications and tracking support capability of the MSFN will be adequate to support the space vehicle during the earth orbital coast phase of any single mission of the first four AAP missions. However, because portions of the space vehicles from the first four AAP missions will be tied together in the joint missions and will be active simultaneously, the communications and tracking support capability of the MSFN must be compared to the communications and tracking support requirements of the overall cluster. It should be remembered that, in addition to supporting the overall cluster, the MSFN is required to support simultaneously an Apollo lunar landing mission and up to three Apollo Lunar Surface Experiment Packages(ALSEP).

When the CSM, the LM/ATM, the Airlock and S-IVB stage Workshop are in a clustered configuration and are active, four VHF PCM/FM telemetry links, two UHF PSK/FM up-data links, two USB PM links and one USB FM link (and possibly, but not likely, a C-band radar link) will require support by the MSFN. It is assumed that the RF links from any launch vehicle are inactive and that the LM&SS rack is inactive (in current configuration LM&SS rack must be hardlined into the CSM to have access to an RF transmission and reception capability).

Two of the VHF PCM/FM telemetry links and the two USB PM links contain real-time housekeeping data (or mission control data). It should be noted that most stations of the MSFN are equipped with only 3 PCM decommutators (see Table 4.1).

Four spacecraft modules in the cluster are capable of being commanded from the Earth, the CSM (USB PM link), the LM (a second USB PM link), the ATM (UHF PSK/FM up-data link), and the Airlock (a second UHF PSK/FM up-data link). In order for a particular station of the MSFN to have the capability for commanding each spacecraft module immediately sequentially, the station must have a dual USB transmission capability and a UHF up-data transmission capability and also be provided with the capability of receiving and decommutating telemetry from each spacecraft module for up-data verification. As can be seen from Figure 4.1 not all stations of the MSFN have these capabilities.

Similarly, simultaneous tracking of the CSM and the LM via the USB system when both spacecraft are within the beamwidth of a single S-band antenna requires that the MSFN station must have a dual USB transmit and receive capability. There is a possibility that the CSM used for the AAP mission will be equipped with a C-band tracking transponder system, thereby permitting simultaneous tracking of the CSM by a C-band radar and of the LM by the USB system by stations of the MSFN equipped with a C-band radar and a USB system.

The additional telemetry links from and the command links to the cluster of spacecraft modules above the number of links to be supported in a nominal mission of the Apollo Program will impose a heavier load on the Remote Site Data Processor (RSDP) and the Command Data Processor (CDP) in each of the stations of the MSFN and on the communications and data links connecting the stations of the MSFN with the MCC-H.

As is apparent from the above statements, the stations of the MSFN will have their limitations in supporting the first four AAP missions without modification. However, before a complete assessment of the impact on the existing MSFN caused by the communications and tracking support requirements of the first four AAP missions, the operational communications and tracking support requirements (in addition to the functional communications and tracking requirements) must be defined. These operational support requirements as a function of mission phase would include:

(a) minimum number of voice, real-time telemetry, command and tracking contacts and minimum time duration of each contact per orbit and/or maximum time between such contacts,

(b) maximum time between tape recorded data dumps,

(c) identification of real-time mission control data monitoring and processing requirements and real-time tracking data processing and monitoring requirements,

(d) identification of requirements for transmission of up-data to more than one spacecraft module immediately sequentially, and

(e) identification of communications and tracking support priorities, if any, for Apollo lunar landing missions, AAP Earth orbital missions, and ALSEP transmissions.

The impact on the MSFN can then be determined by examining these operational requirements in the light of existing support capabilities of each of the MSFN stations and of line-of-sight coverage of the various spacecraft modules provided by the respective MSFN stations as a function of the phase of the nominal mission.

A preliminary set of requirements on the various sites of the MSFN to augment the communications and tracking support capability of the MSFN have been defined for the early AAP missions. These new requirements appearing in the December 21, 1966 preliminary issue of the Apollo Applications Program Support Requirements Document include:

(a) One MSFN site is required to support only one mission (may consist of many related spacecraft modules such as the cluster) at any given time and is required to have a turnaround time from one mission to another of 15 minutes or less.

(b) The Bermuda and Antigua USB sites are to be modified into dual (uplink only) USB sites.

(c) In general, one additional high speed data (HSD) circuit is required between each station and the stations of the MSFN to accommodate the expected higher volume of processed telemetry data to be transferred to MCC-H.

(d) The data handling equipment at dual USB sites is required to have the capability of selecting, decommutating, and processing in real-time any combination of three of the received PCM data streams (a desirable capability for single USB sites).

(e) The RSDP at every USB site should have the capability to store up to six HSD-type data transmission formats for instantaneous callup of any three for simultaneous use.

Since it would require at least 4 PCM decommutators to handle the real-time PCM telemetry links from the cluster as stated earlier, it appears that current operational planning will use a special remote support assignment technique (some sites are assigned to support in real-time a different set of links) or will time-share PCM decommutators at a site with two different PCM data streams.

5.0 Potential Problem Areas

The most basic of the problem areas is the absence of a definitive set of functional requirements for communications among the Airlock, the CSM, the LM, the ATM rack, the LM&SS rack, and the MSFN and a definitive set of operational requirements for communications and tracking support by the MSFN and MCC-H to permit mission control during each of the first four AAP missions separately and during the corresponding joint missions. Similarly, there is a lack of a definitive set of experiment data transfer requirements as a function of mission phase. (For instance, what will the communications requirements be for the LM&SS rack after it has been docked to the cluster?)

Largely as a result of absence of these requirements, little or no communications equipment trade-offs have been made in an attempt to achieve a possibly more efficient communications systems configuration for the space vehicle modules during the early AAP missions. Consequently, each of the space vehicle modules was treated as an independent entity and a communications system configuration was chosen for each providing large capabilities in the hope that the capabilities provided by the proposed implementation would be sufficient to meet any requirements which might be imposed. Alternatives to the current communications systems configuration implementation plan for the space vehicle modules and possible trade-off considerations are discussed in Section 6.0.

A brief discussion of some of the more specific problem areas appear in the following paragraphs.

5.1 EVA Voice Communications and Voice Conferencing Communications

The communications system configuration currently being incorporated in the Airlock by MAC includes a double sideband amplitude modulated (DSBAM) voice transceiver (used in Gemini) operating at a receiver and transmit frequency of 296.8 MHz (simplex operation) which is compatible with one of the modes of operation of the VHF DSBAM voice communications system of the CSM and the LM. All voice communications between crew members within the Airlock or S-IVB Workshop and those in the CSM or LM would be accomplished through use of this simplex RF communications link. A potential problem area immediately presents itself during periods of extravehicular activity when it is remembered that the Apollo space suit backpack voice communications system operates in either of two duplex modes (transmit at 296.8 MHz and receive at 259.7 MHz - primary mode; transmit at 259.7 MHz and receive at 296.8 MHz - backup mode) but cannot operate in a simplex mode. Since two receivers and two transmitters are available, this problem could be eliminated by a redesign of the backpack switching.

There is a problem in providing voice conferencing of three stations each with an RF duplex voice communication capability operating on the same two frequencies (the case of two crewmen involved in extravehicular activity with one crewman remaining in the CM). A similar problem in providing the voice conferencing capability will occur when one crew member is occupying the LM, one crew member is occupying the CSM and one crew member is occupying the Airlock or S-IVB Workshop. It should be noted that true conferencing capability could only be provided with each of the stations having an RF simplex (push-to-talk button or voice operated switch to key the transmitter) voice communication capability and some discipline of the crew members at the various stations to prevent keying of their transmitter when someone else is talking. The voice communications conferencing requirements for AAP should be made more explicit. In particular, it should be made clear whether the voice conferencing capability implemented in the Apollo Program when two crewmen are external to the LM on the lunar surface (not full duplex conferencing) will meet the requirements of AAP.

5.2 Telemetry Systems

5.2.1 Department of Defense Objective to Vacate the VHF Telemetry Band

The current objective of the Department of Defense is to vacate the 225 to 260 MHz frequency band for telemetry transmissions from spacecraft and aircraft by the year 1970. Authorization to use certain VHF telemetry frequencies after the year 1970 would have to be obtained because the Airlock cluster mission could conceivably not be completed prior to 1970.

5.2.2 Negative Circuit Margins for Airlock Telemetry Systems

The Gemini VHF telemetry transmitter with an RF output power of 2 watts using an omni-directional antenna on a space vehicle in conjunction with existing earth-based stations cannot provide sufficient communications performance margin to permit the transfer of a 112.64 kilobit per second PCM bit stream from the Airlock to the earth-based station over a slant range of 1400 nm, corresponding to the slant range at the horizon between the station and a space vehicle in a circular earth orbit of 270 nm (altitude required to achieve an Airlock-S-IVB/IU earth orbital lifetime of at least 18 months).

5.3 Communications and Tracking Support by the MSFN

5.3.1 Tracking of the S-IVB-Airlock Vehicle

There has been no requirement defined for an active radar transponder to be carried by the Airlock to facilitate tracking of the Airlock cluster by earth-based stations. However, tracking of the S-IVB/IU and Airlock combination during earth orbital coast for defining and updating the orbit ephemeris of the combination may be accomplished by:

(a) cooperative tracking of the C-band radar transponder located in the IU until S-IVB/IU power supply depletion (occurs approximately 7 hours after launch) or until the SLA panels are folded back approximately 180 degrees from original position,

(b) cooperative tracking of the Unified S-band (USB) transponder or possibly a C-band radar transponder in the CSM when the CSM is docked with the Airlock (consideration is also being given to adding a C-band transponder to the CSM for AAP missions) or of the USB transponder in the LM when the LM is docked with the Airlock, and

(c) C-band radar skin tracking of the S-IVB/IU and Airlock combination when neither the CSM nor the LM is docked with the Airlock.

5.3.2 Time Shared Operation of the MSFN in Support of the AAP Cluster

There is a requirement for the MSFN to support simultaneously the AAP cluster mission, an Apollo lunar landing mission, and up to three ALSEP transmissions. The existing capabilities of the MSFN will not be sufficient to support more than one mission at a time by any single station; consequently a system of priorities must be developed for time-sharing the existing support capabilities among missions in lieu of the much too costly solution of expanding the support capability of the individual MSFN stations.

5.3.3 Insufficient PCM Decommutation Support Capability in the MSFN

With the current configuration of the communications systems for the cluster mission, four PCM data streams contain mission control data and require real-time decommutation and processing. Most of the stations of the MSFN have the capability to decommutate and process data from only three PCM data streams.

5.4 Space Vehicle Antenna Coverage

The provision of sufficient antenna pattern coverage to permit communications between the MSFN and each of the spacecraft modules in the cluster (Airlock, CSM, LM, ATM, etc.) during the nominal mission will be a major problem. For instance, the location of the LM S-band and VHF antennas will be badly masked and of little use, the Airlock antennas will be partially masked by the LM/ATM, the CSM, and the S-IVB mounted solar panels, and the CSM S-band antennas will also be partially masked.

The complexity of the antenna configuration makes it a necessity for a development program to be undertaken to configure an antenna system for the cluster taking into consideration the planned mission attitude profile and for a test program to be implemented to verify the antenna configuration. The most promising solutions which have been proposed or discussed include (a) putting the antennas on long booms to avoid interference from various space vehicle structures, and (b) using the solar panels as the ground plane for the antennas and placing the antennas at the most removed part of the solar panel to minimize interference from various space vehicle structures (ATM rack antennas being implemented in this manner).

5.5 Rendezvous of CSM and Airlock and S-IVB Stage Workshop Combination Without Active Spacecraft Radars

There has been no requirement defined for an active radar transponder to be carried by the S-IVB/IU and Airlock combination to assist the CSM in rendezvous and docking with the Airlock. Successful rendezvous of the CSM with the S-IVB/IU and Airlock combination may possibly be accomplished via ground-based calculations and subsequent command of CSM maneuvers complemented by visual data from the on-board crew; however, further study of this method of rendezvous seems to be indicated.

5.6 Biomedical Data Requirements

The biomedical data requirements must be more definitive. For instance, will the biomedical data transmitted from the portable life support system (PLSS) used by the crewmen performing extravehicular activities in the Apollo Program meet the requirements for the same situation in AAP ? In addition, when two crewmen are performing extravehicular activities simultaneously will continuous biomedical data be required from both crewmen or will a single biomedical data channel time-shared by the two crewmen (as in the Apollo Program) be sufficient?

5.7 Radio Frequency Interference and Electromagnetic Compatibility

Although the possible electrical interfaces between any two of the space vehicle modules will not be overly complex, care must be exercised to assure the electromagnetic compatibility of the modules in a clustered configuration with special attention given to possible radio frequency interference problems likely to be present in the cluster because of the multiple RF radiations from the cluster and the various locations of antennas on the irregularly shaped cluster.

5.8 Data Transfer Requirements from the Experiments

A definitive set of requirements on the magnitude of the data from experiments is required as a function of mission phase in order to enable evaluation of the capacities of the telemetry links from the various space vehicle modules. Special attention must be given to obtaining the requirements from the transfer of data not originating in the experiment packages but required for the proper interpretation of the data gathered from the experiment.

6.0 Alternatives to the Currently Planned Configuration of the Communications Systems of the Space Vehicle Modules in the Overall Cluster

Possible trade-off considerations of the planned implementation of the telemetry, up-data, and voice communications functions of the various space vehicle modules comprising the overall cluster are discussed in the following paragraphs.

6.1 Telemetry

6.1.1 Integration of Airlock and S-IVB Stage Workshop Telemetry with the CSM Systems

As stated earlier, the transfer of real-time data and recorded data playback simultaneously from the Airlock and S-IVB Stage Workshop combination to the MSFN is required during the mission phase when the CSM is docked with the Airlock and the transfer of certain critical operational data on Airlock systems to the MSFN is required during selected time periods of the mission when the CSM is not docked to the Airlock (i.e. earth orbital storage phase of the mission, etc.). Consequently, the Airlock and S-IVB stage Workshop combination must be provided with an independent telemetry transmission capability. As a result, no further discussion will be given to the time-shared use of the CSM S-band FM transmitter to transfer telemetry from the Airlock and S-IVB stage Workshop combination to the MSFN.

6.1.1.1 Time-Shared Use of the S-IVB/IU VHF Telemetry Systems

Since the requirements for the transfer of data on the performance of systems in the S-IVB/IU to the MSFN during earth orbital coast are sharply reduced below the requirements for telemetry from the S-IVB/IU after approximately 7 hours after launch, the use of the VHF telemetry transmitters of the S-IVB/IU for the transfer of data from the Airlock to the MSFN appears attractive. However, the following items must be considered:

(a) The current plan for deployment of the SLA panels by folding them back against the S-IVB/IU will seriously degrade the coverage provided by the S-IVB/IU VHF antennas which would require relocation of the antennas to the aft end of the S-IVB stage.

(b) An electrical interface would be created between the Airlock and the S-IVB/IU in order to (1) transfer power to operate the environmental control system of the IU and the RF transmitters, (2) transfer the data streams to be transmitted and (3) switch the inputs to the VHF transmitters.

(c) The S-IVB/IU VHF telemetry transmitters would have to be qualified for 18 month operation (although not continuous) or sufficient spares would have to be provided.

(d) Authorization to use certain VHF telemetry frequencies after 1970 would have to be obtained.

6.1.1.2 Airlock Contained S-Band PCM/FM Telemetry Transmitters

The use of S-band PCM/FM Telemetry transmitters on the Airlock appears to be somewhat attractive because no VHF telemetry links would be required which is consistent with the objective of vacating the 225 to 260 MHz frequency band for telemetry by 1970. However, due to the possibility of simultaneously conducting the Airlock cluster mission, and Apollo lunar landing mission, and ALSEP transmissions, the already existing interference problems in spectrum occupancy at S-band (the frequencies assigned to Apollo, 2270 to 2290 MHz) when attempting to support two LMs, two CSMs, and ALSEP simultaneously would be further complicated by selecting two more frequencies in this frequency band for Airlock and S-IVB Workshop telemetry transmissions. It is possible that a set of priorities could be worked out to permit time-sharing of the frequencies in the S-band when the space vehicles and ALSEP are within the beamwidth of a single ground-based antenna.

Selection of two S-band frequencies outside of the 2270 to 2290 MHz frequency band for use by the telemetry transmitters on the Airlock would solve the interference complication problem in the Apollo band but may interfere with JPL (2290-2300 MHz) or DOD (2200-2270 MHz) programs. In any event, the use of any such S-band frequencies would require special authorization. Furthermore, if S-band frequencies below 2270 MHz were authorized for use in this application, the S-band receiver and exciter systems of the MSFN stations would require modification.

Installation of a Block II-CSM S-band FM transmitter in the Airlock for transmission of real-time and recorded data would minimize ground station modifications and reduce possible interference. However, recorded playback telemetry and television transmissions from the CSM or LM and SS rack data relay through the CSM would not be possible except through time-sharing of the frequency. In addition, the FM transmitter requires a 400 Hz 3 phase power supply (not planned for the Airlock) in addition to 28 volts dc power supply (planned for the Airlock) for operation.

6.1.1.3 Airlock Contained Unified S-Band System

The use of a USB transponder on the Airlock would be more attractive than the use of S-band telemetry transmitters because the up-data requirements as well as any tracking requirements which may develop for the Airlock and S-IVB Workshop can be fulfilled by the USB system. However, there will be more severe interference problems than those discussed in Section 6.1.1.2 and there will be more extensive modifications required in the earth-based stations, including the provision of a third set of coherent PM frequencies, than those discussed in Section 6.1.1.2.

6.1.2 Apollo Telescope Mount (ATM) Rack Telemetry

As stated earlier, the transfer of real-time data and recorded data playback simultaneously from the ATM rack to the MSFN is required during the active portion of the ATM mission.

6.1.2.1 Time-Shared Use of the LM Unified S-Band System

Since the descent stage and the ascent propulsion capability have been removed from the LM for its application in the ATM mission, it seems logical to assume that the LM systems housekeeping data transfer requirements are significantly reduced. In an effort to reduce the number of telemetry links which must be decommutated and processed in real-time by the stations of the MSFN, it appears attractive to investigate the feasibility of combining the required real-time data from the LM and from the ATM into a single NRZ PCM bit stream of 51.2 kilobits per second which could be transmitted to the MSFN on the 1.024 MHz telemetry subcarrier via either the LM FM or PM link. (LM USB system does not have the capability of transmitting both FM and PM carriers simultaneously.) In the FM link Application, the playback of recorded data from the ATM rack could be transmitted at baseband (in place of television) simultaneously with the real-time data on the telemetry subcarrier. Thereby two VHF PCM/FM telemetry links would be eliminated and would be in keeping with the objective of vacating the VHF telemetry frequency band by 1970. However, this arrangement would have the disadvantage that the MSFN would not have the capability to track the LM/ATM combination. During the periods of the LM/ATM mission when it is docked to the CSM or to the multiple docking adapter on the cluster, the inability of the MSFN to track the LM/ATM would not be a serious problem because the CSM could be tracked by the MSFN.

If tracking of the LM/ATM combination should become a requirement, the PM carrier of the USB system could be used to transmit the composite LM and ATM rack real-time data to the MSFN. The playback of recorded data from the LM could be accomplished as currently planned, or, more attractively, by time-sharing the USB link with the tracking function (switch between FM and PM transmission modes in the LM).

6.1.2.2 ATM Contained S-Band PCM/FM Telemetry Transmitters

See Section 6.1.1.2 since the same discussion is applicable. It should be noted that the interference problems in the allocated S-band frequency band would only be increased if the ATM telemetry system frequencies were only changed from VHF to S-band.

6.1.2.3 ATM Contained Unified S-Band System

See Section 6.1.1.3 since the same discussion is applicable.

6.1.3 Overall Cluster Integrated Telemetry

Combining the data required for transmission to the MSFN from each of the space vehicle modules in the overall cluster into a single data stream is attractive from the standpoint of reducing the number of RF links radiated from the overall cluster but would not reduce the number of telemetry transmitters on each module because telemetry transmission is required from the modules during periods of the mission when not docked with the cluster. In addition, problem areas will exist, not the least of which will be the development of the telemetry system capable of performing the complex function of formatting and programming the data (both real-time and playback) and transmitter capable of transmitting the data stream.

6.2 Up-Data

6.2.1 Airlock and S-IVB Stage Workshop Up-Data

As stated earlier, the transfer of commands from the MSFN to the Airlock is required during selected time periods throughout the entire approximately 18 month orbital lifetime of the Airlock and S-IVB stage Workshop. Consequently, the Airlock and S-IVB/IU combination must be provided with an independent up-data reception and decoding capability. As a result, no consideration will be given to the time-shared use of the up-data system of the CSM for transferring commands from the MSFN to the Airlock and S-IVB stage Workshop combination.

6.2.1.1 Time-Shared Use of the S-IVB/IU Up-Data Receiver and Decoder

Since the requirements for the transfer of commands to the S-IVB/IU are small, being zero after approximately 7 hours after insertion into Earth orbit, the use of the 450 MHz up-data receiver and decoder of the S-IVB/IU appears feasible and their use would eliminate the need for a 450 MHz up-data receiver and decoder and associated antennas on the Airlock. However, the following factors would have to be considered before a final decision is made:

(a) The current plan for deployment of the SLA panels will seriously degrade the coverage provided by the UHF antennas on the IU.

(b) An electrical interface will be created between the Airlock and the IU for the transfer of power to the IU to operate the up-data receiver and decoder and the environmental control system of the IU and for the transfer of commands to the Airlock.

(c) The IU UHF up-data system would have to be qualified for 18 months operation (continuous) or sufficient spares would have to be provided.

6.2.1.2 Airlock Contained Unified S-Band System

See Section 6.1.1.3 since the same discussion is applicable.

6.2.1.3 Airlock Contained S-Band Command Receiver

The Airlock could be equipped with the S-band command receiver developed for use in ALSEP which would eliminate the need for a 450 MHz up-data receiver. The use of the ALSEP command receiver would have added advantage of providing all USB stations of the MSFN with the capability to transmit commands or up-data to the Airlock (using a different vehicle address than ALSEP) and not just the lesser number of USB stations of the MSFN which are also equipped with a UHF up-data transmission capability (see Table 4.1). However, using the MSFN to ALSEP command link to transmit commands to the Airlock would require a different mode of operation of the USB system of the MSFN station than used for the support of the CSM and the LM which would possibly be a difficult operations problem.

The same advantage would be obtained if the CSM USB up-data receiver were used instead of the ALSEP command receiver without incurring the disadvantages of using the ALSEP command receiver except that a new vehicle address would be needed to route commands properly to the Airlock rather than to the CSM.

6.2.2.2 ATM Contained Unified S-Band System

See Section 6.1.1.3 since the same discussion is applicable.

6.2.2.3 ATM Contained S-Band Command Receiver

See Section 6.1.1.3 since the same discussion is applicable.

6.3 Integrated Voice Communications

A requirement has been defined for a voice conference capability among the three crew members at all times, including those instances when any have egressed from the CM and entered the Airlock, the LM; or the S-IVB stage tank Workshop or are performing extravehicular activity, and among the three crew members and ground-based stations whenever the ground-based station is within line-of-sight of the cluster. An alternative to the currently planned implementation of this requirement which appears to be gaining favor and which most probably will be implemented is described below.

A distribution bus with multiple disconnects to permit the crew members to hardline their microphone output and headset inputs into the bus could be provided in the Airlock, the S-IVB Workshop, and the LM-ATM which would allow crewmen in the Airlock, the S-IVB Workshop, or the LM-ATM to communicate. (This bus could also be used to transfer biomedical data from crewmen hardlined into the bus to the multiplexer encoder system of the Airlock for processing for subsequent transmission to ground-based stations.) One end of the voice distribution bus could then be plugged into one of the audio centers in the CM in place of the umbilical cable of a crewman who would be normally located at that position when not external to the CM. Thus, the distribution bus would be effectively a long umbilical cable from the crewmen to the audio center and the procedures for voice conferencing and voice recording would be identical to those procedures currently in effect in the Apollo Program, including those instances when one crew member is involved in extravehicular activity. Unless the hatches are left open in the CM and the LM, connectors will have to be provided in these modules to enable this hardline voice communications conferencing concept to be implemented, thereby eliminating the need for an RF voice communications capability on the Airlock and S-IVB Workshop combination. The 19-pin connector on the CSM to permit CSM-LM hardline connections could possibly be modified to permit connection of the distribution bus to the audio center within the CM if the CM hatch was required to be kept closed.

7.0 CONCLUSIONS AND RECOMMENDATIONS

As a result of the preliminary review of the communications and tracking systems of the ground-based support and space vehicle elements to be used during the first four missions of the Apollo Applications Program (including joint missions involving elements from two or more of the first four missions) from both functional and operational veiwpoints, several problem areas of major import to the basic program were noted which require early attention and resolution. These include:

(a) the development of a comprehensive and definitive set of functional requirements for communications and tracking (tracking, up-data, telemetry, biomedical data, data recording and playback, voice communications, voice relay, voice conferencing, etc.) between the MSFN and the various space vehicle modules for separate and joint missions,

(b) the development of a comprehensive set of operational requirements for communications between the space vehicle elements and the MSFN (and MCC-H) as a function of mission phase to permit mission control by MCC-H and to ensure overall mission success (including the experiments); and

(c) the definition of the requirements imposed by the planned experiment packages for the transfer of data between the space vehicle modules and the MSFN as a function of mission phase and the definition of the requirements for the transfer of peripheral data required for the assessment of the results of the experiment but not actually included in the data output from the experiment package.

The review also revealed potential problem areas which will require study after the requirements for the missions have been more clearly defined, including:

(a) trade-off analysis of the communications system implementation to maximize communications efficiency with minimum impact on existing support systems, cost, and schedule,

(b) space vehicle antenna system design to provide required coverage,

(c) analysis of the effects of meeting the objective of vacating the VHF telemetry frequency band (225 to 260 MHz) by 1970,

(d) analysis of electromagnetic compatibility of the space vehicle modules in a clustered configuration with emphasis on radio frequency interference,

(e) determination of the performance margin of the communication links,

(f) investigation of the CSM and Airlock/S-IVB Workshop rendezvous methods,and

(g) an analysis of the concurrent support by the MSFN of a cluster mission of the AAP, a manned lunar landing mission and up to three ALSEPs.

In conjunction with the suggested communication systems equipment implementation trade-off study, the following alternatives to the current equipment implementation of the communications systems of the space vehicle modules should be evaluated:

(a) use the LM USB system FM transmitter for the transfer of LM and ATM real-time telemetry (time-division multiplexed on the telemetry subcarrier) and ATM recorded data playback (at baseband),

(b) time-shared use of the LM USB up-data receiver by the LM and the ATM,

(c) use a CSM type USB receiver to permit up-data reception in the Airlock and use different address prefixes to the commands for CSM and for Airlock, and

(d) use a hardline bus to provide voice communications conferencing among crewmen in the LM, the Airlock, the S-IVB stage workshop, and the CM, and use the CSM USB system to include the MSFN in the voice conference loop with the crewmen.

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